FlightLinux Project

Onboard LAN
Technical Report

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Revision History

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Introduction

The intent of this technical report is to define the LAN (local area network) architectures that will be supported by the FlightLinux software product. An onboard LAN in a standard configuration will simplify the interface between various spacecraft components. A LAN consists of the lower (physical) layer, and perhaps two levels of software protocol imposed on the physical layer. The advantages of running a routable protocol over the physical LAN will be explored.

This is considered to be a living document, that will be updated as required to encorporate new and evolving information. Sections marked "to be supplied" will be completed and supplied in subsequent revisions of this document. At this writing, a meeting on IP-over-CCSDS is scheduled to be held at JPL momentarily, followed by a meeting with the Internet Engineering Task Force (IETF) in London in August, 2001.

Background

This work was conducted under task NAS5-99124-297, with funding by the NASA Advanced Information Systems Technology (AIST) Program, NRA-99-OES-08. The work is conducted by personnel of QSS Group, Inc. in partnership with NASA/GSFC codes 586 (Science Data Systems), Code 588 (Advanced Architectures and Automation), and code 582 (Flight Software).

The FlightLinux project has the stated goal of providing an on-orbit flight demonstration of the software within the contract period. Numerous other Linux efforts exist within the GSFC flight software community. Currently, FlightLinux is being developed for a flight test on the UoSat-12 spacecraft, which is already on-orbit. A UoSat-12 testbed facility owned by the OMNI Project (Code 588) is being used for development. This testbed incorporates synchronous serial, CAN bus, and ethernet interfaces.

Management Summary

This report discusses the existing and projected LAN architectures for use onboard spacecraft, and the support that is or will be available under FlightLinux. It discusses the benefits and importance of an onboard LAN architecture. Given Linux onboard the spacecraft, support for a LAN becomes relatively easy. Extending the onboard LAN to other spacecraft units in a constellation also becomes feasible, as does having the spacecraft operate as an Internet node.

Interface between spacecraft components is usually provided by point-to-point connections, or a master-slave bus architecture. The use of a LAN onboard is not yet common. This is partially due to the lack of space-qualified components.

The avionics bus MIL-STD-1553 and its optical derivative, 1773, are commonly used between spacecraft components. This bus, used in thousands of military and commercial

aircraft has a legacy of applications behind it. Also, 1553 is transformer-coupled and dual-redundant, providing a level of failure protection. The raw data rate is 1 megabit per second. It is a master-slave architecture.

For point-to-point connections that do not require the complexity of a 1553/1773 connection, a synchronous serial connection such as RS-422/23 with a bit rate around 1 megabit per second is typically used.

A LAN-type architecture is typically used in office and enterprise environments (and spacecraft control centers). It provides a connection between peer units, or clients and servers. The typical LAN used a coax or twisted pair connection at a transmission rate of 10 megabits per second, a twisted pair connection at 100 megabits per second, or optical at 155 megabits per second, with higher speeds possible.

Usually, a LAN is configured with a repeating hub, or a central switch between units. The standard protocol imposed on the physical interface is TCP/IP - transmission control protocol/internet protocol, although others are possible (even simultaneously). The TCP/IP protocol has become a favored approach to linking computers around the world. The protocol is supported by Linux and most other operating environments. The use of TCP/IP first appeared in 1969.

The OSI model and Network Protocols

To be supplied

Server Based networks

To be supplied

TCP/IP Protocol, and the OSI Model

To be supplied

Bridges and Routers

Bridges operate between networks, at the OSI Data Link Layer (level 2). Switches also operate at level 2. Routers operate at OSI level 3 - the Network layer.

Routable versus non-routable protocols

A communications protocol that contains a network address as well as a device address, allowing data to be routed from one network to another, is called a routable protocol. If the protocol does not contain a network (level 3) address, it is not routable. A non-routable protocol does not incorporate an addressing scheme for sending data from one network to another. The TCP/IP protocol is routable.

References:

1) Good background material can be found at:
http://marconi.com/html/education/webbasedlantheory.htm
2) Habraken, Joe, Practical Cisco Routers, Que Books
3) Naik, Dilip C., Internet Standards and Protocols
4) OSI Model, http://www.erg.abdn.ac.uk/users/gorry/eg3561/intro-pages/osi.html

Discussion of Near-term onboard LAN options

The following Onboard LAN options for the physical layer are derived from the Spacecraft onboard payload data accommodations section of the Rapid-I and -II programs, (see http://rsdo.gsfc.nasa.gov), and from common and emerging commercial LAN architectures These can be considered typical of near-term spacecraft architectures for onboard data transfer.

1. MIL-STD-1553b/1773

The effective data throughput of the legacy 1553 bus is around 300 kilobits per second. The bus architecture has a single master with multiple slaves, and uses dual-redundant transformer-coupled buses. This technology has an extensive experience base in avionics and space. 1773 is the optical version of twisted pair 1553, and operates at higher rates. It should be noted that a component may be on multiple 1553 buses simultaneously, and may serve as master of one, and slave on others. In essence, master units can initiate communication, where slave units speak when spoken to.

Because 1553 is a master-slave architecture, it does not map well to a client-server type model. However, the Spacecraft Onboard Inter Face (SOIF) group, under the auspices of the CCSDS committee, has been looking at these issues. It is not impossible to run a protocol such as TCP/IP over master-slave architectures, although it is not straight-forward.

The use of 1553/1773 is facilitated by the availability of space qualified hardware.

references

1) 1553 Product Handbook, United Technology Microelectronic Center, 1991.

2) MIL-STD-1553 Designer's Guide, 3rd. edition, ILC Data Device Corporation, 1990.

3) SOIF: ftp://ftp.estec.esa.nl/pub/ws/wsd/ccsds/ccsdsoif/intro.htm

2. EIA-RS-422

RS-422 is a serial point-to-point physical interface over wire. It has an effective maximum throughput to 5 megabits per second. Usually, a synchronous serial protocol such as (High level data link control) HDLC is imposed over RS-422.

3. EIA-RS-485

RS-485 is an upgraded version of the RS-422 protocol, specifically designed to address the problem of communication between multiple devices on a single data line. It is a balanced transmission system that is virtually identical to RS-422 with the important addition of the ability to allow up to 32 devices to communicate using the same data line. Thus any point can directly communicate with each other, taking on the role of master and slave as needed. This is achieved by the use of tri-state drivers which are controlled by a programmable handshake line to ensure that only one device acts as a driver at any one time. Communication can be initiated from any point on the line. A protocol such as HDLC can be imposed on RS-485.

Reference:

http://www.erg.abdn.ac.uk/users/gorry/eg3561/dl-pages/hdlc-framing.html

4. CAN

CAN is the Controller Area Network, originally developed for automobiles and industrial use. It uses a two-wire differential bus. It is a serial protocol, with data rates to 1 Mbit/sec. It implements distributed real time control and multiplexing. CAN represents the Data link and physical layer of the ISO networking model. It is used by Surrey Satellite Technology Ltd. for UOSat-12 and SNAP-1, and is supported by Linux drivers.

The Controller Area Network (CAN) specification defines the Data Link Layer, ISO 11898 defines the Physical Layer. The CAN interface is an 2-wire asynchronous transmission scheme controlled by start and stop bits at the beginning and end of each character. This interface is used, employing serial binary interchange. Information is passed from transmitters to receivers in a data frame. The data frame is composed of an Arbitration field, Control field, Data field, CRC field, ACK field. The frame begins with a ‘Start of frame’, and ends with an ‘End of frame’ space. The data field may be from 0 to 8 bits. The frame check sequence is derived from a Cyclic Redundancy Code (CRC).

References:

1) http://www.interfacebus.com/Design_Connector_CAN.html

2) ISO 11898/11519

5. USB

The Universal Serial Bus (USB) has been developed and standardized under the collaborative efforts of a number of hardware and software manufacturers to address the limitations and complexity associated with adding expansion devices to the personal computer. However, the use of USB is not limited to Intel or X86 architecture. The USB specification describes a standard for attaching peripheral devices to computers that can be used with many processor types including the more capable embedded processors that control many modern devices or systems. In addition, USB can be used to interconnect computers, or to connect mass storage devices to processors.

Traditionally there has been a limitation on the number of peripheral devices that can be attached to a computer. The more common methods of delivering and receiving data from a computer require it to provide dedicated physical and logical assets for each connected input/output (I/O) device. Physical assets include the electrical connectors and circuitry required to attach devices to the computer, while logical assets include the methods required to signal the computer that an external device is ready to deliver or accept information. External devices are defined as any add-on device, whether it is plugged into a card slot inside the computer's cabinet or attached to a connector on the exterior of the cabinet.

The lack of expansion capability for inexpensive computers, coupled with a flood of new or planned add-on devices, particularly medium speed multimedia peripherals such as scanners, cameras, digital audio, and telephony equipment drove the development of the Universal Serial Bus. The USB allows the attachment of up to 127. A number of the 127 devices will actually be expansion ports that allow connection of additional devices in a tiered manner. USB is supported by the Microsoft Windows 98/ME/2000 and Apple Macintosh OS9 operating systems. The Linux operating system also provides partial USB support. Common hardware support for USB is provided on virtually all Intel architecture PCs built after 1997 and on the Apple Computer iMac, PowerMac G4, and iBook products.

The ability to connect 127 devices to a single USB port is accomplished by using methods that have more in common with computer networking models than with previous types of input/output connection for peripherals. Communication is between adjacent layers in the stack as well as between the corresponding layers of the transmitting and receiving stacks. The emerging USB-II protocol will increase the existing transmission speed from the existing 1.5/12 Mbps to 480 Mbps. USB-II devices and support are just appearing in the marketplace.

Reference:

1) http://mes.loyola.edu/FACULTY/PHS1.HTM - the pages on USB were compiled by Paul M. Reeves, for Loyola College, Dept. of Engineering Science, Graduate School in partial fulfillment of the requirements for a Master's Degree, under P. Stakem, Advisor.

6. FireWire

IEEE-1394, also known as FireWire-3, is a high-speed serial bus standard developed for consumer electronics. FireWire is to be easy to use and configure, but is more complex than SpaceWire (discussed in Section 7), which has lower latency with higher scalability. Since FireWire and SpaceWire are aimed at different applications, they also have different specifications. Firewire is a registered trademark of Apple-Computer, Inc.

FireWire is a bus (master-slave) architecture using cable media. A tree or daisy chain topology is required. It uses a 6-wire cable: 2 for power supply & 2 pairs for data: Each pair transmits one Data or Strobe Signal in differential form in one direction. Links are half-duplex: i.e. data can be transmitted only in one direction at the time. The data rates are specified at 100 Mbps, 200 Mbps, and 400 Mbps.

FireWire devices in military-grade (but not in radiation tolerant grade) are available now. Current FireWire connectors are not suitable for space applications.

References

1) IEEE-1394, http://www.1394ta.com/

7. Spacewire

SpaceWire is a network for space applications composed of nodes and routers interconnected through bi-directional high-speed digital serial links using cable media.

SpaceWire is an upgrade of the high-speed digital serial links defined in the DS-DE part of the IEEE-1355 Standard. SpaceWire is based on the DS-DE (DataStrobe-Differential Ended) part of the IEEE 1355 Standard, and its main characteristics are:

- high-speed (> 100 Mbps) bi-directional
- point-to-point serial interface
- can be used at 10 meters distance or more
- simple interface using Data-Strobe
- Low-Cost, Low-Latency, Scalable

Data rate is not specified in the Standard (it is a function of skew and jitter). At present, devices operate at 155-200 Mbps.

SpaceWire is a derivative of the Inmos Transputer link architecture, which was a 10 Mbps asynchronous serial interconnect, that could be switched. The transparent physical layer of SpaceWire is compatible with higher level protocols (e.g. ATM, SCI, Ethernet).

References:

1) http://www.estec.esa.nl/tech/spacewire/index.html

2) http://grouper.ieee.org/groups/1355/index.html, IEEE Std 1355-1995 Standard for Heterogeneous InterConnect (HIC) (Low Cost Low Latency Scalable Serial Interconnect)

8. 10baseT, 100 base T Ethernet

Of all the protocols, Ethernet is the most widely used. It provides network access using carrier sense multiple access with collision detection (CSMA/CD) as a strategy. The nodes on the network listen before transmitting. If two nodes happen to transmit at the same time, the communication is garbled. This is detected, and each transmitter waits a random time, and tries again. Ethernet can be run across a variety of media, including optical fibre, to gigabit speeds.

Standards:

1. Ethernet 802.3 - Novel Netware 2 &3

2. Ethernet 802.2 - Novel Netware 4 and 5

3. Ethernet SNAP - AppleTalk

The OMNI Project, IP in space experience.

To be supplied

References:

1. The OMNI Project webpage: http://ipinspace.gsfc.nasa.gov/

2. *Internet Access to Spacecraft*, James Rash, Ron Parise, Keith Hogie, Ed Criscuolo, Jim Langston, Chris Jackson, Harold Price, published at the Small Satellite 2000 conference in Logan, Utah.

3. *Internet Technology on Spacecraft*, James Rash, Ron Parise, Keith Hogie, Ed Criscuolo, Jim Langston, AIAA paper 2000-5295

The UoSat-12 Onboard Computer configuration

The UoSat-12 onboard computer, which will become the onorbit testbed for FlightLinux, is an embedded Intel 80386EX processor, with 4 megabytes of main memory, 128 megabytes of extended memory, and 4 synchronous serial interfaces, dual CAN bus interfaces, and an ethernet port. A Linux interface developed by the OMNI Project will for the synchronous ports will be adapted for FlightLinux. Similarly, existing device drivers for the CAN bus will be ported to Linux. The ethernet port is standard, and should be directly supported by FlightLinux.

Reference: http://www.sstl.co.uk/missions/subpage_missions_uosat_12.html

The OMNI FlatSat Configuration

To be supplied

Expeience with LAN Physical layer options onboard spacecraft

MIL-D-1553b/1773	extensive experience base
EIA RS-422, -485	common use for point-point
CAN	limited use, in flight
USB	no known usage
FireWire	experimental
SpaceWire	experimental. ESA favored
10Base-T	experimental

Interaction of the Onboard Lan with CCSDS Protocols

To be supplied